A Preliminary Investigation Of Model Evaluation Data Needs

John Irwin[1], William Petersen[2], and Steven Howard[2]

1) John S. Irwin and Associates*, Raleigh, NC
2) NOAA Atmospheric Sciences Modeling Division**, RTP, NC
**In partnership with the U.S. EPA,

Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
October 17-20, 2006
Sissi (Malia), Crete, Greece

* Email: jsirwinetal@nc.rr.com

- Models of plume/puff transport and diffusion describe only a portion of the real-world variability.
- Our goal was to develop a quantitative characterization of the unresolved variability and then investigate the data needs for field tracer studies of dispersion for model evaluation investigations.
- How many times do you have to roll a pair of dice to determine that they are “fair”? **Experimental investigations of processes affected by random effects must insure the sample size is sufficient for the intended purposes.**

RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

$$C \propto \frac{Q}{U\sigma_x\sigma_y\sigma_z} F_y\left(\frac{y}{\sigma_y}\right) F_z\left(z,\sigma_z,H_e,Z_i\right)$$

In this investigation, we focused on the following:

- The unresolved variability about the lateral Gaussian plume profile, Fy.

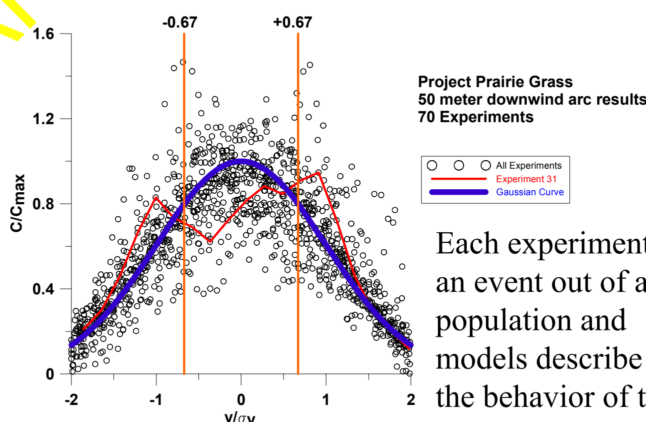
- The unresolved variability in the lateral and vertical puff growth rates, σy and σz.

- The variability in the trajectory of the dispersing material relative to the puff dispersion.

Composite Analysis for Project Prairie Grass Experiments
All the "scatter" about the blue line (Gaussian fit) is what a Gaussian plume model does not characterize.

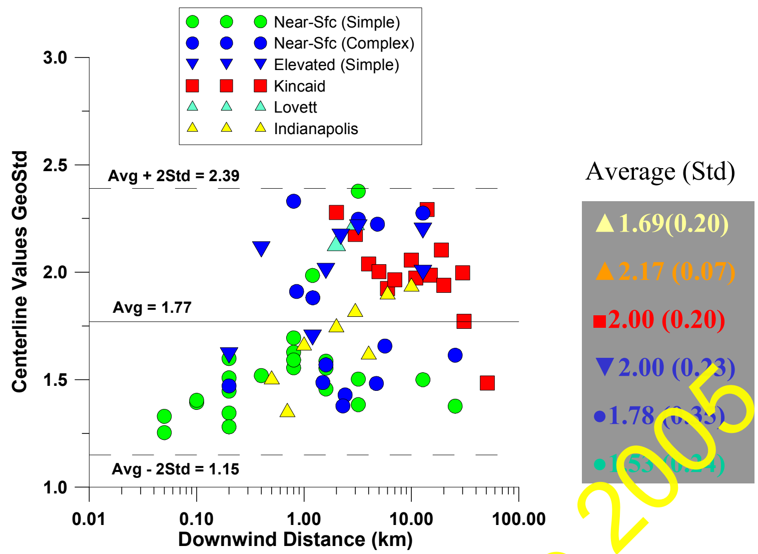
13 Experiments

Looked at the scatter about Gaussian fits to tracer results having dense sampling along arcs.

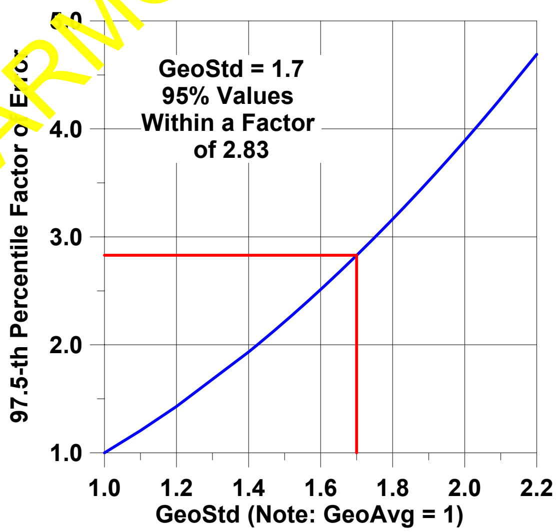


Each experiment is an event out of a population and models describe the behavior of the ensemble mean

RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions



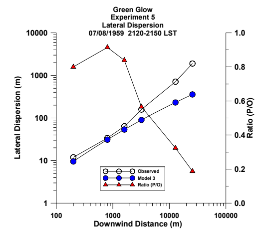
RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

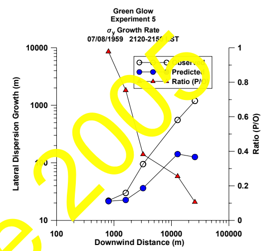


RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

Variability in Puff Dimensions

- 25 experiments
- Looked at the scatter in ratios of observe divided by the predicted (O/P) growth rates of σ_y and σ_z of tracer dispersing downwind over several sampling arcs out to 5km
- There were seen to be two sources of variability: random biases (GeoStd = 1.48) from one site to the next, and random variations (GeoStd = 2.00) on average at any one site

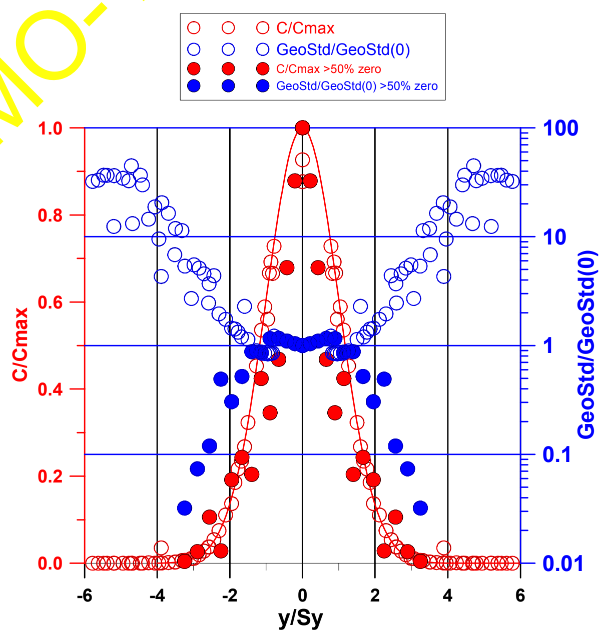




Here we see a summary for the first 12 hours of a puff (neutral conditions, winds of 3 m/s).

The concentrations have been divided by Cmax at for each hour and the GeoStd values have been divided by the central value of the GeoStd for each hour which equaled 1.37.

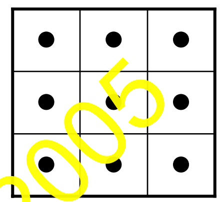
Mostly affects near field dispersion.



Wind Field Variability
Cell to Cell Wind Field Differences

- Analyzed the differences seen in the initial nine-cell wind directions:
  - 10-m winds: Julian days 159-186
    - Stdev Wd was < 4 degrees
    - Stdev Ws was < 1 m/s
  - 75-m winds: Julian days 155-192
    - Stdev Wd was < 6 degrees
    - Stdev Ws was < 1 m/s

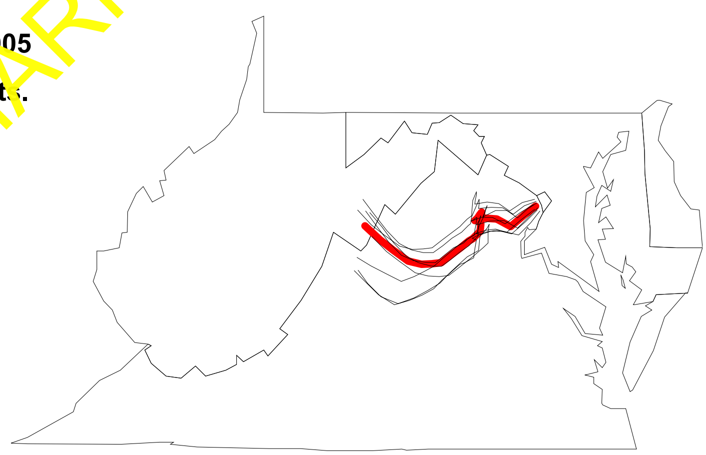
0000Z Eta-12km Forecast



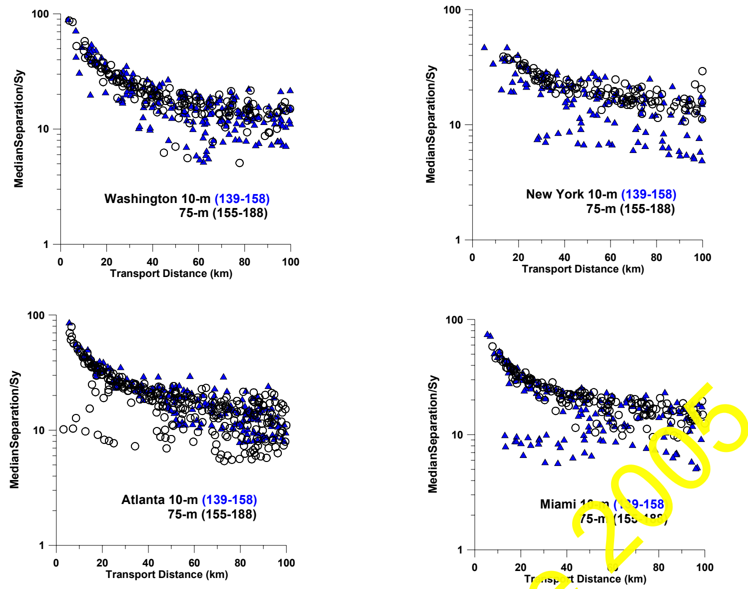
Puff Trajectory Variability

May 19, 2005

DCA results.



RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions



RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

Summary

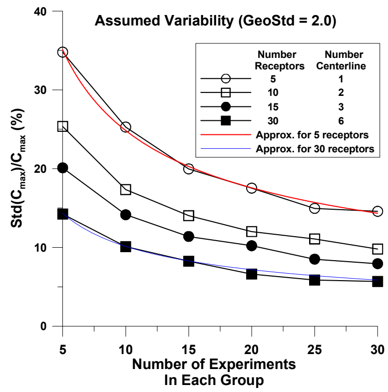
- Non-Gaussian variability can be described as having a log-normal distribution with a GeoStd of about 2.0.
- The variations in the growth rate have little affect on the centerline concentrations once the mean growth rate starts to slow down, which is around 1 to 3km downwind.
- The variation in trajectories is much larger than the actual puff dimensions.

RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

Receptor Spacing

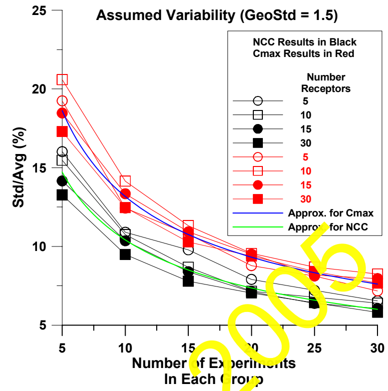
Num Receptors	SFC 7°	ELEV 14°
5	6	12
10	3	6
15	2	4
30	1	2

Uncertainty in Tracer Cmax



5 receptors = 6 or 12 degrees
30 receptors = 1 or 2 degrees

Uncertainty in Modelled Cmax



ASTM Bias in Modelled Cmax is +15% to -20%

RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

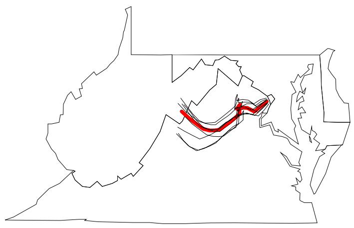
The End

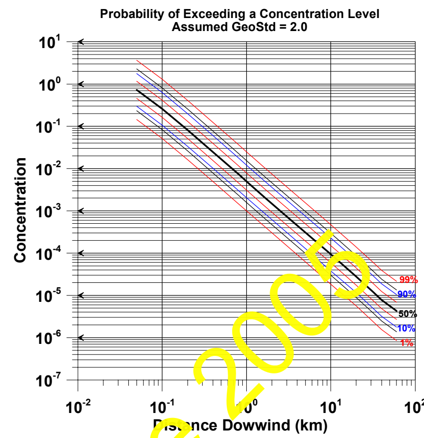
Thank you for your attention

DISCLAIMER *The research presented here was performed under the Memorandum of Understanding between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and under agreement number* DW13921548. *This work constitutes a contribution to the NOAA Air Quality Program. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views.*

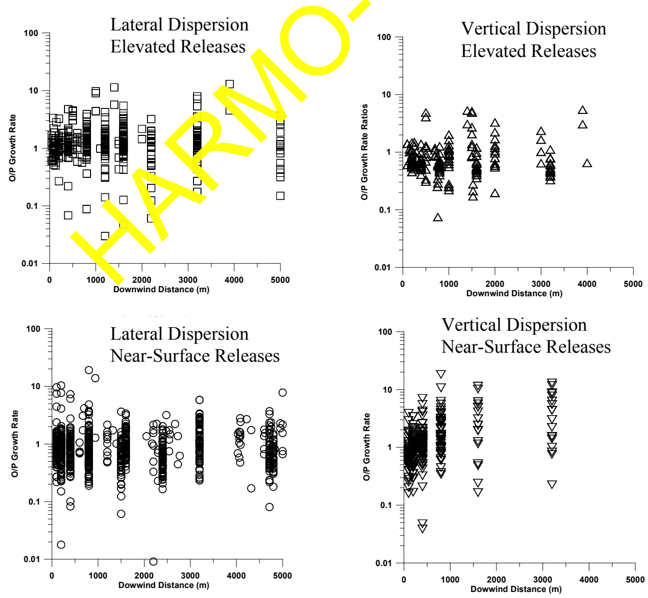
RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

Example Emergency Response Guidance





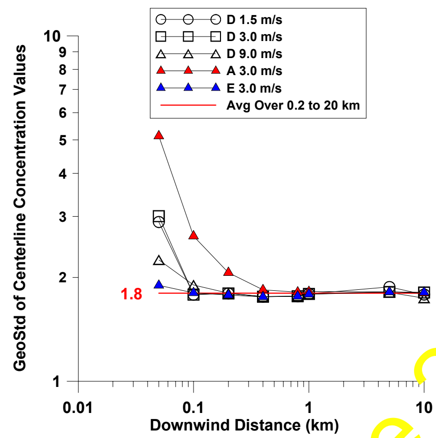
Together the two plots depict the variability to be seen in the trajectory paths and in the centerline concentration values.



Scatter plots of the ratio of observed and predicted growth rates (P/.O).

There does not appear to be any strong dependence on distance.

Variation of the Centerline GeoStd as a function of wind speed and stability, when the growth rates of σ_y and σ_z are variable and non-Gaussian effects are also simulated.

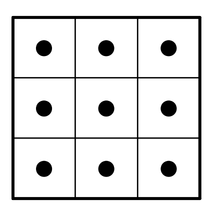


RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

Puff Trajectory Variability

- Used 0000Z 24-hour Eta-12km forecast.
- Trajectories were developed:
  - 10-m winds for Julian days 139-158
  - 75-m winds for Julian days 155-188
- Nine cells (eight surrounding central release point) to provide a preliminary look at the consequences of wind field variability.
- Scatter in trajectories was compared to puff widths to see if the difference in trajectory locations was larger than the puff width.

0000Z Eta-12km Forecast

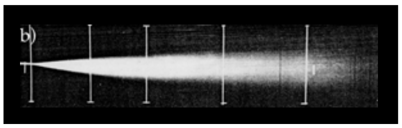


RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

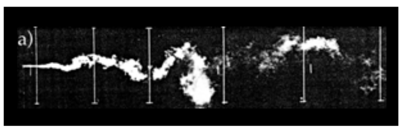
Concentration Fluctuations

– for toxic gases – instantaneous peaks can be lethal … these are short term phenomenon … turbulence controlled … most models provide the "time-average" result……remember, models cannot predict exactly what actually will be seen… models can only predict the "average characteristics" of what is to be seen….

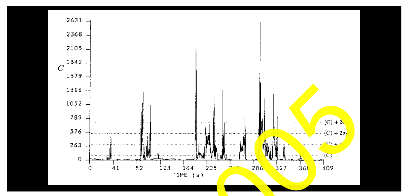
time-averaged picture



real-time picture



USEPA Fluid Modeling Facility

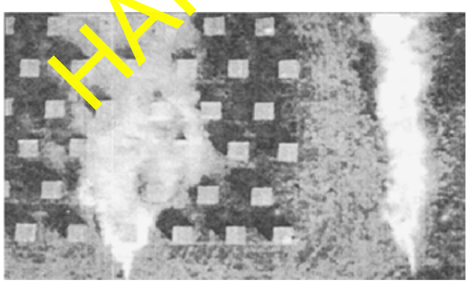


concentration time-series measurements

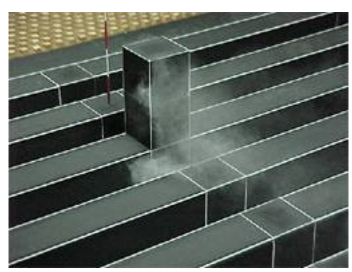
RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

Buildings increase mixing in complex ways

Models cannot predict exactly what is actually seen… models can only predict the "average characteristics" of what is to be seen…..



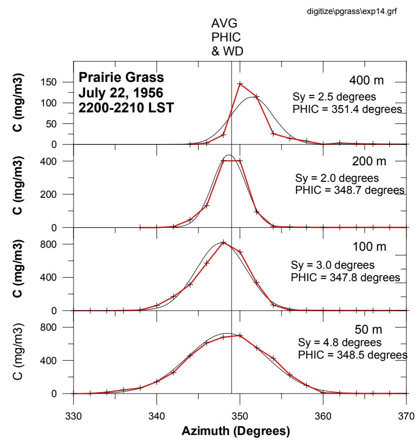
USEPA wind tunnel experiment, plan view. Dispersion over building arrays and unobstructed fetch.



USEPA wind tunnel experiment, release at street level in canyon.

RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

What Do “Real” Plumes Look Like?



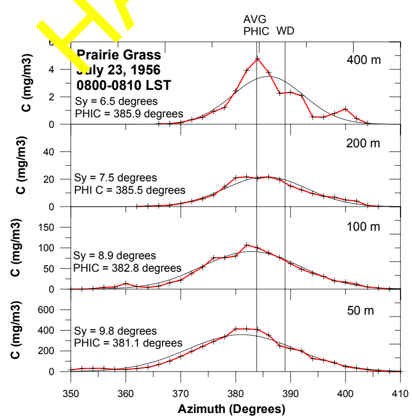
Analysis of 10-minute concentration values seen for July 22, 1956 from 2200 to 2210 LST.

Results shown are for first four arcs. Solid lines with symbols show measured sulfur-dioxide values. A Gaussian fit is shown for each arc. The resulting plume centerline position, PHIC, and lateral dispersion, Sy, is shown for each arc.

The vertical solid line illustrates not only the transport wind direction indicated by the 2-m wind at the release, but also the average of the PHIC determined individually for each arc. Notice that PHIC does not really describe where the centerline will be.

What Do “Real” Plumes Look Like?

Project Prairie Grass involved a point source release 0.5 meters above the ground. The experiments were conducted in a manicured nearly-flat field near O’Neil Nebraska.

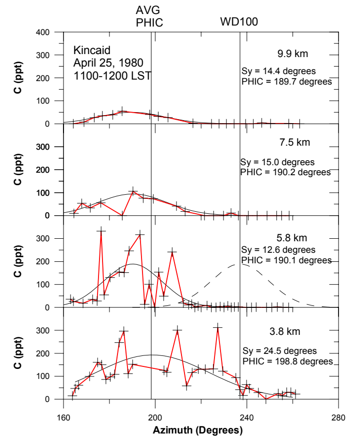


Analysis of 10-minute concentration values seen for July 23, 1956 from 0800 to 0810 LST.

Results shown are for first four arcs. Solid lines with symbols show measured sulfur-dioxide values. A Gaussian fit is shown for each arc. The resulting plume centerline position, PHIC, and lateral dispersion, Sy, is shown for each arc.

The two vertical solid lines illustrates the transport wind direction indicated by the 2-m wind and the average of the PHIC determined individually for each arc.

The Kincaid tracer experiments involved injecting SF6 into the gas exiting up a power-plant smoke stack. The smoke stack was 183 m tall, and the gases were hotter than the air, rose and leveled off at about 300 m above the ground.



.Analysis of 1-hr concentration values seen for April 25, 1980 from 1200 to 1300 LST. Results are shown for four arcs.

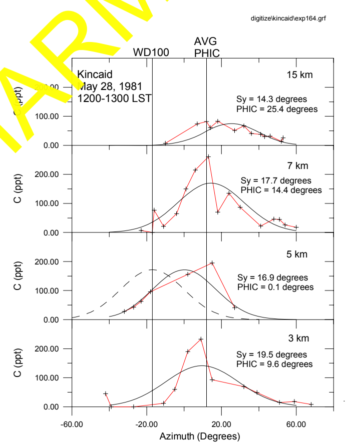
Solid lines with symbols show measured SF6 values. A Gaussian fit is shown for each arc. The resulting plume centerline position, PHIC, and lateral dispersion, Sy, is shown for each arc.

The two vertical solid lines illustrates the transport wind direction indicated by the 100-m wind and the average of the PHIC determined individually for each arc.

The dotted line (second arc) shows the effect of differences in transport between what is estimated by a wind direction at the release and what actually occurs.

RESEARCH & DEVELOPMENT

Building a scientific foundation for sound environmental decisions



Analysis of 1-hr concentration values seen for May 28, 1981 from 1200 to 1300 LST. Results are shown for four arcs.

Solid lines with symbols show measured SF6 values. A Gaussian fit is shown for each arc. The resulting plume centerline position, PHIC, and lateral dispersion, Sy, is shown for each arc.

The two vertical solid lines illustrates the transport wind direction indicated by the 100-m wind and the average of the PHIC determined individually for each arc.

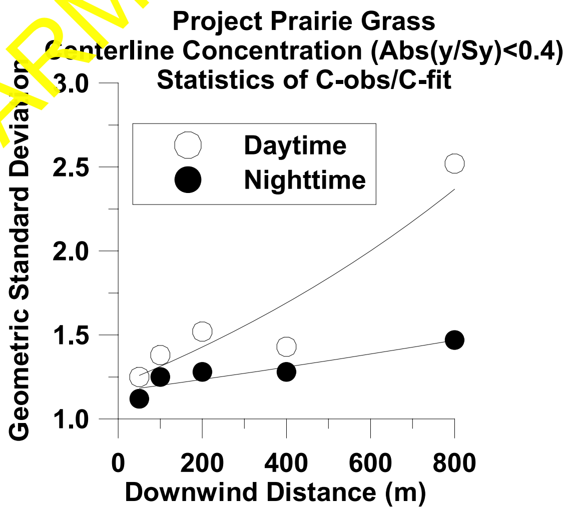
RESEARCH & DEVELOPMENT

Building a scientific foundation for sound environmental decisions

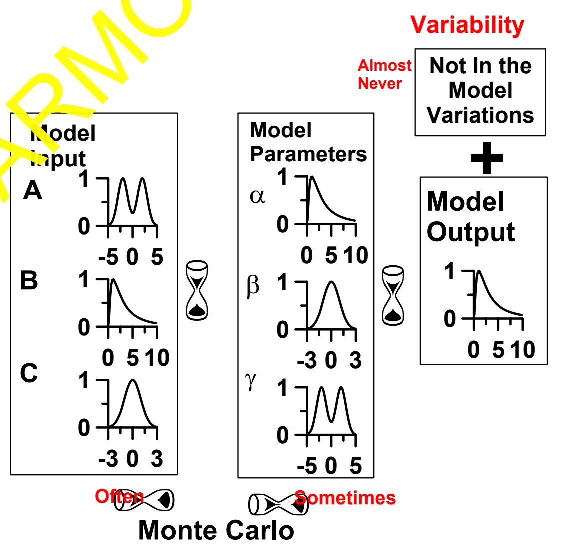
Summary of Centerline Concentration Fluctuations

Experiment/ Category	Number of Arcs	Average	Standard Deviation	Geometric Average	Geometric Standard Deviation
Near-Surface (Simple	23	0.93 (0.05)	0.36 (0.11)	0.86 (0.06)	1.53 0.24)
Near-Surface (Complex)	14	1.02 (0.12)	0.63 (0.36)	0.88 (0.06)	1.78 (0.35)
Elevated (Simple)	8	0.99 (0.08)	0.64 (0.14)	0.81 (0.08)	2.00 (0.23)
Kincaid	15	1.01 (0.11)	1.25 (0.49)	1.08 (0.20)	2.00 (0.20)
Lovett	2	0.94 (0.18)	1.05 (0.06)	0.92 (0.13)	2.17 (0.07)
Indianapolis	8	1.08 (0.10)	0.76 (0.23)	0.99 (0.04)	1.69 (0.20)

Variability In Prairie Grass Centerline Concentrations



Just How Variable Are Wind Directions and Wind Speeds?



$$C_O(\alpha) = \overline{C_O(\alpha)} + \Delta c' + c''(\alpha, \beta)$$

where

$\overline{C_o(\alpha)} =$ concentration for α-conditions averaged over all possible values of 👓

$\Delta c' =$ represents the measurement errors.

$c''(\alpha, \beta) =$ represents the variability due to unresolved physics and processes ("β-effects" or ignorance).

$$C_m(\alpha) = \overline{C_o(\alpha)} + \overline{f(\alpha)} + \Delta\alpha'$$

where

$\overline{C_m} = \overline{C_o(\alpha)} + \overline{f(\alpha)} =$ model's average concentration for conditions α.

$\overline{f(\alpha)} =$ the average deterministic error in the model's estimate for conditions α.

$\Delta\alpha' =$ the effects of uncertainty and unresolved variability in specifying the model's inputs.

$$C_m(\alpha) = \overline{C_o(\alpha)} + \overline{f(\alpha)} + \Delta\alpha'$$

- A common misconception is that characterization of $\Delta\alpha'$ (e.g. Monte Carlo simulation of input uncertainties) is a characterization of $c''(\alpha,\beta)$.
- Characterizing variability due to unresolved physics, $c''(\alpha,\beta)$, can really only be deduced through an analysis that involves observations!

RESEARCH & DEVELOPMENT

Building a scientific foundation for sound environmental decisions